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Introduction

The scallop, *Pecten maximus* (L.), is usually found recessed in sediments of sand and silt, with the flat upper shell valve level with the sea bed and covered by a fine layer of bottom deposit (Plate I). Scallop stocks around

Plate I. Underwater photograph showing undisturbed scallop (arrowed) recessed in the sea bed.

Britain are exploited by towing dredges with a toothed bar to lift out the recessed animals. The efficiency of these dredges is low. Baird (1955, 1959), for example, estimated that between 5 and 20% of the scallops in the path of the dredge are caught in the course of a tow. This observation led Baird to design a new dredge which was about three times as efficient on smooth sand. Rolfe (1969), using two different methods, obtained estimates of 24 and 33% efficiency for the "Baird" dredge. The commercial dredge is also selective by virtue of both tooth spacing and mesh size, so that only a small proportion of small scallops (< 80 mm in size) in the path of the dredge is caught (Baird and Gibson, 1956; Drinkwater, 1974).

The traditional, or standard, dredge used mainly on smooth substrata has a fixed tooth bar. In Scotland this has largely been replaced on rougher grounds by dredges fitted with a spring-loaded toothed bar which 'gives' when obstacles are encountered, thus reducing damage (Fig. 1). The operation and efficiency of this dredge are described in this paper and compared

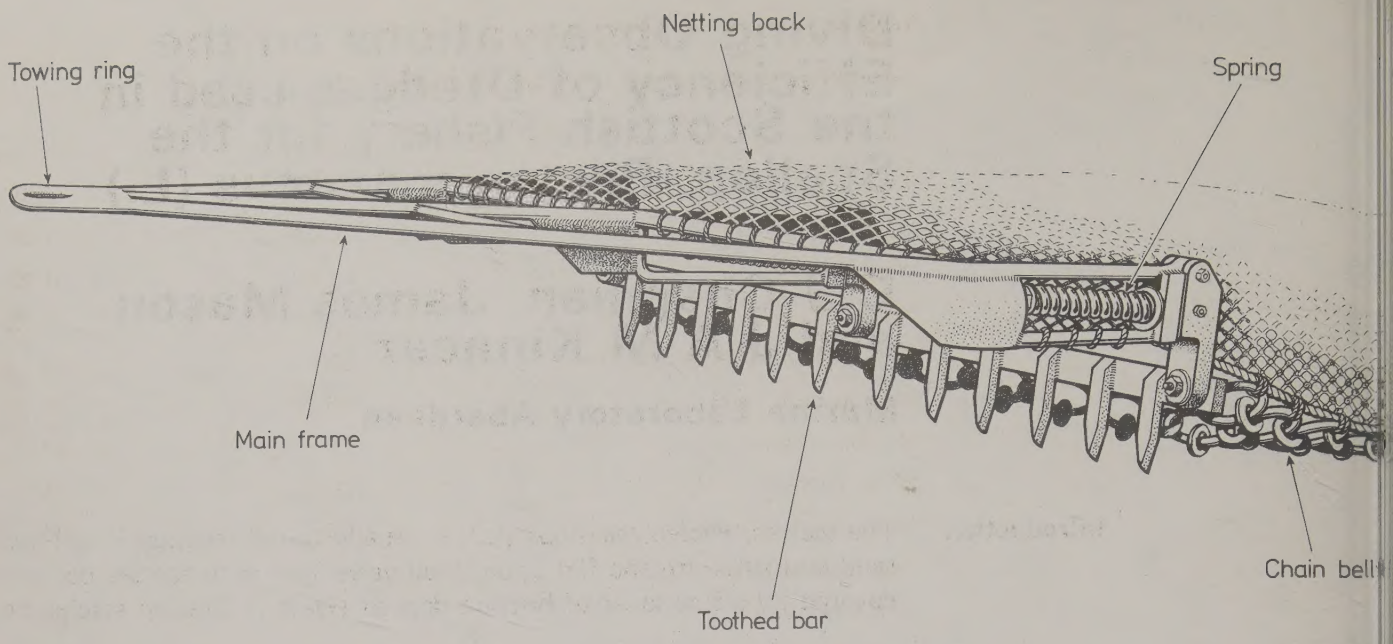

Figure 1. Diagram showing the main features of the spring-loaded tooth dredge.

with standard fixed bar dredges. A preliminary account of some aspects of this work was given by Mason, Chapman and Kinnear (1976).

Previous workers on pectinids have determined dredge efficiency indirectly by comparing the catch per unit area fished with the density of animals determined independently (Dickie, 1955; Baird, 1959; Caddy, 1968, 1971; Rolfe, 1969). The method described in this paper involved divers swimming along the distinct track marks left by the dredge and collecting all the scallops missed by the gear, so that the proportion of scallops caught was determined directly. In addition the subsequent mortality of scallops missed by the dredges was compared with that of scallops caught and others collected from unfished areas.

Methods

Most work was done using the research vessel 'Goldseeker' on commercial scallop beds at a depth of 12-25 m in Claonaig Bay (55° 44.4'N 05° 23.3'W) in September 1974 and off Skipness (55° 45.5'N 05° 21.0'W) in September 1975. The sea bed consisted of sand, shells, small stones and dead coralline algae (*Lithothamnion*).

Gear

The dimensions of the standard and spring-loaded dredges are compared in Table I. Both dredges consisted of a triangular frame with a mouth opening 1.22 m wide, a bar with 12 teeth and a bag with a belly of steel rings (83 mm internal diameter) and netting back (80 mm stretched mesh). The spring-loaded dredge (Fig. 1) was heavier than the standard and its teeth were narrower and more than 50% longer. The compression in the springs was about 70% of maximum, giving an opposing load of 360 kg force per 10° deflection of the teeth (H.Cogan, personal communication).

Some observations were made with 'Goldseeker' towing a single standard dredge, but usually two dredges were attached to a metal towing bar with a bridle and a single wire warp. In 1974 a 1.22 m bar was used but in 1975 a longer (2.1 m) bar was employed so that the tracks of the two dredges were separate. The height of the longer bar, and hence the angle of attack of the teeth, was kept constant by means of a rubber wheel, 0.45 m in diameter, at each end (Plate II).

Table I

Dimensions of standard and spring-loaded dredges

	Standard	Spring-loaded
Total length (m)	1.96	2.35
Length of bag (m)	0.64	1.06
Width (m)	1.22	1.22
Height of mouth opening (m)	0.15	0.13
Belly ring internal diameter (mm)	83	83
Netting mesh (mm)	80	80
Number of teeth	12	12
Width of teeth (mm)	25	21
Mean length of teeth (mm)	53	86
Mean space between teeth		
at base (mm)	77	80
at tip (mm)	94	97
Angle of attack of teeth		
(to the horizontal when fished with wheeled bar)	67.5°	77.5°
Total weight (kg)	91	110

Plate II. Underwater photograph showing two spring-loaded dredges towed from a bar with rubber wheels to maintain a constant tooth angle of attack.

Procedure

Dredge hauls were normally parallel to the shore to maintain a constant depth and lasted 5-10 min. A buoyed line was anchored to the sea bed at the start of the tow. Usually two divers observed each haul, with one diver holding on to each dredge. The divers carried a small cassette tape recorder in an underwater housing and recorded their observations through a bone-conduction microphone.

When the disturbed bottom deposit had settled, about 20 min after hauling the dredges aboard, the divers examined the tracks marked by the dredges on the sea bed and collected all the scallops missed by the gear. These were

either still recessed in the substratum, having passed between the teeth, or were lying on the substratum in or beside the track (Plate III). In the

a

b

Plate III (a) (b). Underwater photographs showing unrecessed scallops lying in the track of the dredge. Note the edge of the track in (b) indicated by the arrows.

undisturbed population, before dredging commenced, our observations showed that 94% of scallops were recessed in the sea bed. Unrecessed scallops on or near the dredge track were therefore considered to have been originally in the path of the dredges. In 1974 the divers collected all unrecessed scallops found up to 0.3 m away from each side of the track, but in 1975 this was extended to 1 m on each side of the track to improve the accuracy of the results. In the interval between divers' observation of the track, a few scallops may have moved away from the collecting area so that the dredge efficiency may be slightly over-estimated. In 1975, when the longer towing bar was used, there was a gap of 0.9 m between the two dredges; any scallops from this middle ground were assumed to have come from the dredge whose track was nearest to them.

Every scallop caught by the dredge or collected by the divers was measured antero-posteriorly and aged by means of its annual growth rings. The amount of 'trash' (stones, bottom deposit, shell and seaweed) in each dredge haul was weighed by spring balance.

The numbers of scallops collected from the track and adjacent sea bed were added to those caught by the dredge to obtain the total number of scallops originally in the path of the dredge. The percentage efficiency was calculated as:

$$\frac{\text{No caught by dredge}}{\text{No caught + No collected in and near track}} \times 100$$

The distances covered by the dredges were first estimated from 'Goldseeker's' Decca Navigator, but in 1975 a more accurate method was used, in which one diver released small markers at timed intervals along the track. In this way average towing speed and total distance covered by the dredge could be measured accurately. The product of distance and dredge width gave an estimate of the area fished, which was used to calculate the density of scallops.

The work on 'Goldseeker' was supplemented by observations on spring-loaded dredges fished by the commercial vessel 'Accord III' in the vicinity of Port Ellen, Islay (55° 37'N 06° 10'W), in July 1975. Four dredges were towed, two on a bar from each quarter. Warp length was 3-5 times the depth. No wheels were employed on the towing bars so that the angle of attack of the teeth varied during the haul. Dredging took place on several types of sediment ranging from mud through sand and stones to large boulders and occasional rock outcrops. Both divers made observations from the same dredge.

Mortality experiments

It would be useful to know whether scallops taken by the dredge and returned to the sea survive. Estimates of the survival of scallops caught by the dredge were compared with the survival of those collected by divers from the dredge track and from unfished areas. The scallops were brought to the surface and marked, either with a soft pencil on the shell or with a numbered plastic disc glued or wired to the shell. To assess mortality the marked scallops were returned to an unfished area marked off on the seabed and examined periodically. The degree of shell damage was assessed on an ordinal scale from 0 (both valves intact) to 5 (severely damaged-shell broken or hinge damaged). The same scale was used to assess the damage caused by the dredges in all the efficiency hauls.

Results

Population density and size composition

Scallops occurred at all diving depths from 12 to 25 m. The average density at Claonaig in 1974 was about 1 scallop per 8 m^2. A year later this had fallen to about 1 per 32 m^2, presumably as a result of commercial fishing. At Skipness in September 1975 the overall density was about 1 scallop per 5 m^2. Individual density estimates are given in Tables II-IV and are plotted against depth in Figure 2. At Claonaig scallops appeared to be most abundant between 15.5 and 18 m depth (Fig. 2B). Except for one haul, the data for Skipness indicated a more uniform distribution with depth (Fig. 2A).

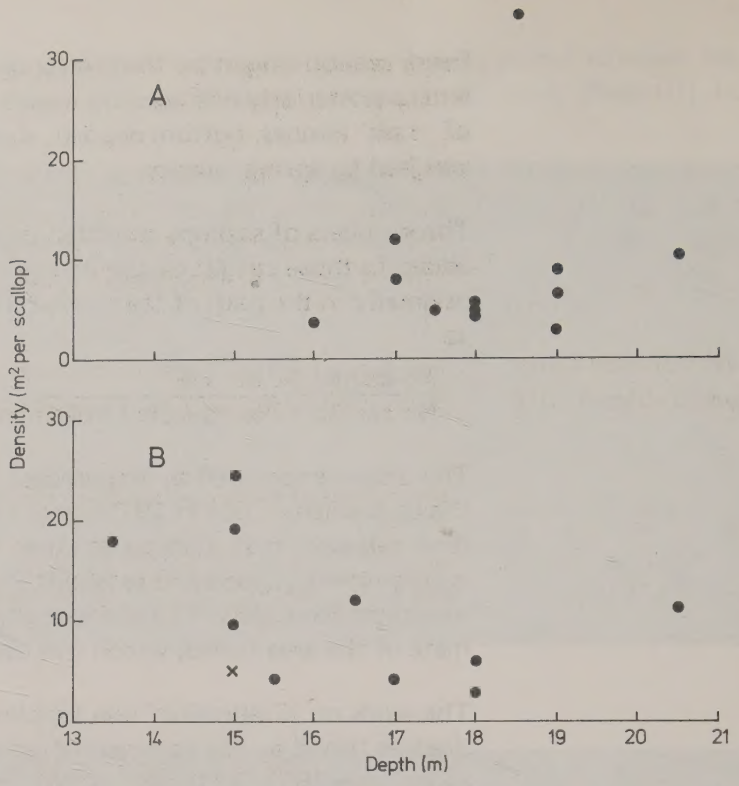

Figure 2. **The density of scallops in relation to depth, (A) Skipness 1975 and (B) Claonaig 1974. In (B) x shows the density observed in a 120 m^2 transect by diving; other data were obtained from the dredge hauls. In (A) the isolated value at 18.5 m depth was obtained in a different area from the other data. Hauls in which the depth range varied by more than 3 m were excluded from both graphs.**

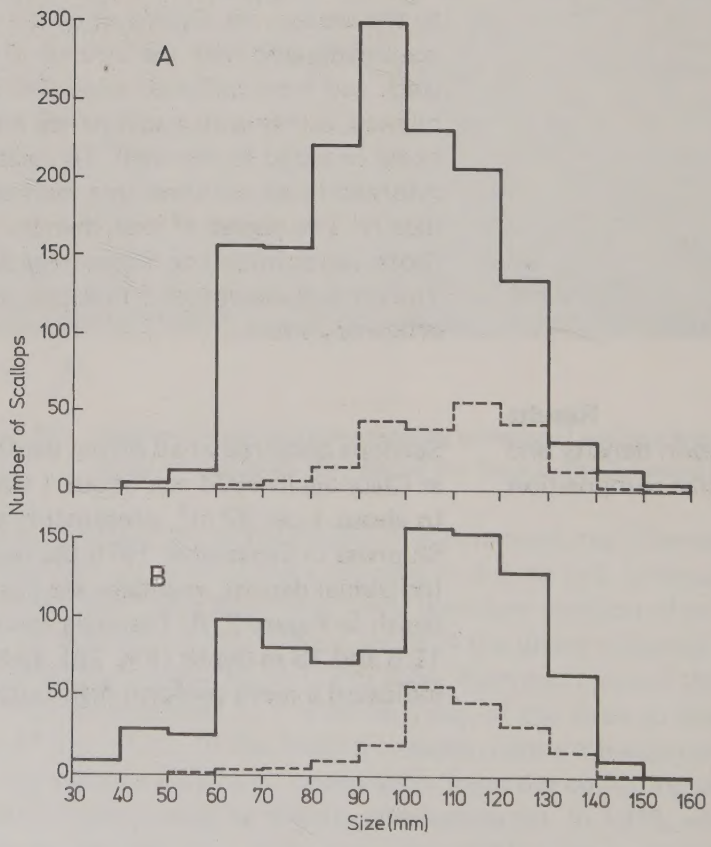

Figure 3. **Histograms showing the size structure of the scallop population (_____) and the proportion of each size caught by the dredges (- - - -) (combined data from all hauls). (A) Skipness 1975, (B) Claonaig 1974. Note that the catches were obtained using standard dredges in (B) and both standard and spring-loaded dredges in (A).**

The size compositions of the populations in the two areas are shown in Figure 3 together with the proportions of scallops in each 10 mm size - group caught by the dredges. Selection by the standard dredge is clearly shown in Figure 3B by the absence of the 60-69 mm mode from the dredge catches. Scallops from 100 to 129 mm predominated in the population at Claonaig in 1974 and those from 80 to 119 mm were most abundant at Skipness in 1975. The efficiency of the dredges was low, particularly for small scallops.

Efficiency of standard fixed bar dredges (Tables II, III)

The short teeth of these dredges dug in up to ½ to ¾ of their length, thus generating a large mound of sediment in front of the toothed bar, most of

Table II

The efficiency of standard dredges towed singly or in pairs at Claonaig, 1974 by FRV 'Goldseeker'

Haul No	No of Dredges	Depth (m)	Towing speed (ms^{-1})	Area fished (m^2)	Density (m^2 per scallop)	Number of Scallops Caught	In and near track	Total	Efficiency (%) Size group ⟨ 80 mm	⟩ 80 mm	overall
1	1	18	0.9	320	6.0	14	39	53	0	49.0	26.0
2	1	14-17	1.2	450	4.1	37	74	111	4.6	40.7	33.5
3	1	18	1.2	450	2.8	23	137	160	5.0	20.0	14.4
4	1	12-20	0.8	290	3.5	6	77	83	0	12.0	7.2
5	1	15	1.1	400	9.6	15	27	42	0	29.5	25.7
6	1	13-18	1.1	400	20.1	4	16	20	—*	20.0	20.0
7	1	15	1.1	400	19.2	2	19	21	0	12.5	9.5
8	2	20-21	0.9	680	11.2	7	54	61	0	13.7	11.5
9	2	15-18	1.0	730	15.3	7	41	48	0	18.4	14.6
10	2	16-18	1.0	730	4.0	43	139	182	7.1	31.0	23.6
11	2	16-17	0.9	680	12.0	19	38	57	0	33.9	33.3
12	2	15	0.9	680	24.4	3	25	28	0	12.0	10.7
13	2	13-14	1.6	680	18.0	7	31	38	0	25.9	18.4
Totals				6890		188	717	905			
Means			1.0		7.6				3.3	27.0	20.7

* No scallops ⟨ 80 mm were caught or found in or near track

Table III

The efficiency of paired standard and modified (winged) fixed tooth dredges, FRV 'Goldseeker' 1975

Haul No	Dredge	Depth (m)	Towing speed (ms^{-1})	Area fished (m^2)	Density (m^2 per scallop)	Number of Scallops Caught	In and near track	Total	Efficiency (%) Size group ⟨ 80 mm	⟩ 80 mm	overall
1	Standard	22	1.6	1220	32.1	6	17	23	0	40.0	26.1
	Winged					1	14	15	0	7.7	6.7
2	Standard	20-21	0.7	642	10.4	4	22	26	0	17.5	15.4
	Winged					5	31	36	21.7	12.9	13.9
3	Standard	15-17	1.0	900	3.6	24	118	142	2.0	25.4	16.9
	Winged					16	94	110	0	20.1	14.6
4	Standard	17-18	0.9	720	4.8	10	50	60	7.7	19.2	16.7
	Winged					22	66	88	4.8	31.3	23.9
5	Standard	18	0.9	640	4.2	19	49	68	50.0	26.6	27.9
	Winged					17	68	85	0	25.8	20.0
6	Standard	18	0.9	350	5.4	8	56	64	0	18.6	12.5
7	Standard	18-19	0.9	340	43.1	0	8	8	0	0	0
Totals				3590*		132	591	723			
Means			1.0		5.2*				3.3	23.3	18.3

Notes With the exception of Haul 1 all hauls were conducted at Skipness. In Hauls 6 and 7 the standard dredge was paired with a spring-loaded dredge.

* excluding Haul 1

which was deposited round the sides of the dredges. At times the mound completely filled the dredge opening (Plate IV), particularly when large stone

Plate IV. Underwater photograph showing the build-up of material, completely filling the mouth of a standard fixed bar dredge.

or shells blocked some of the gaps between the teeth. It was difficult to see what happened to individual scallops, but most appeared to be pushed aside. Several smaller ones (< 90 mm), disturbed by the gear, were seen to swim aside. Clouds of sediment distrubed by the teeth made it impossible to see whether any scallops escaped through the bag meshes. One standard dredge was modified in an attempt to retain scallops pushed aside. A pair of 'wings' were welded on to the sides of the frame extending 0.2 m forward of the toothed bar. These consisted of an outer frame of 20 mm diameter metal rod to which rings (65 mm internal diameter) of the same material were welded to form a lattice.

The dredge tracks were distinct, ridges of sediment being deposited each side (Plate IIIb). Most scallops found in the track had been dug out and only 16% were still recessed. The results for each haul given in Tables II and III show efficiency estimates for two size groups, < 80 mm and $\geqslant 80$ mm long. This division corresponds roughly to that between undersized and marketable scallops and also to the tooth spacing and mesh and ring sizes of the dredge. The efficiency showed large variations from haul to haul, from 7.2 to 35.7% in 1974 and from 0 to 27.9% in 1975. The average efficiency for all sizes of scallops was 20.7% in 1974 and 18.2% in 1975, and for marketable scallops 27.0% in 1974 and 23.6% in 1975. Only 3.3% of the undersized scallops, < 80 mm, were caught.

The addition of wings reduced the amount of sediment pushed aside but created an even greater mound of material in the mouth of the dredge. This resulted in more than 30% more 'trash' being taken but did not increase the catch of scallops (see Table VI).

The efficiency of the standard dredge for different sizes of scallop is shown in Figure 4. The two curves are similar for small scallops but with maximum efficiency at different sizes. This is difficult to account for but may reflect differences in the angle of attack of the toothed bar. Both curves show a decrease in efficiency for the largest scallops.

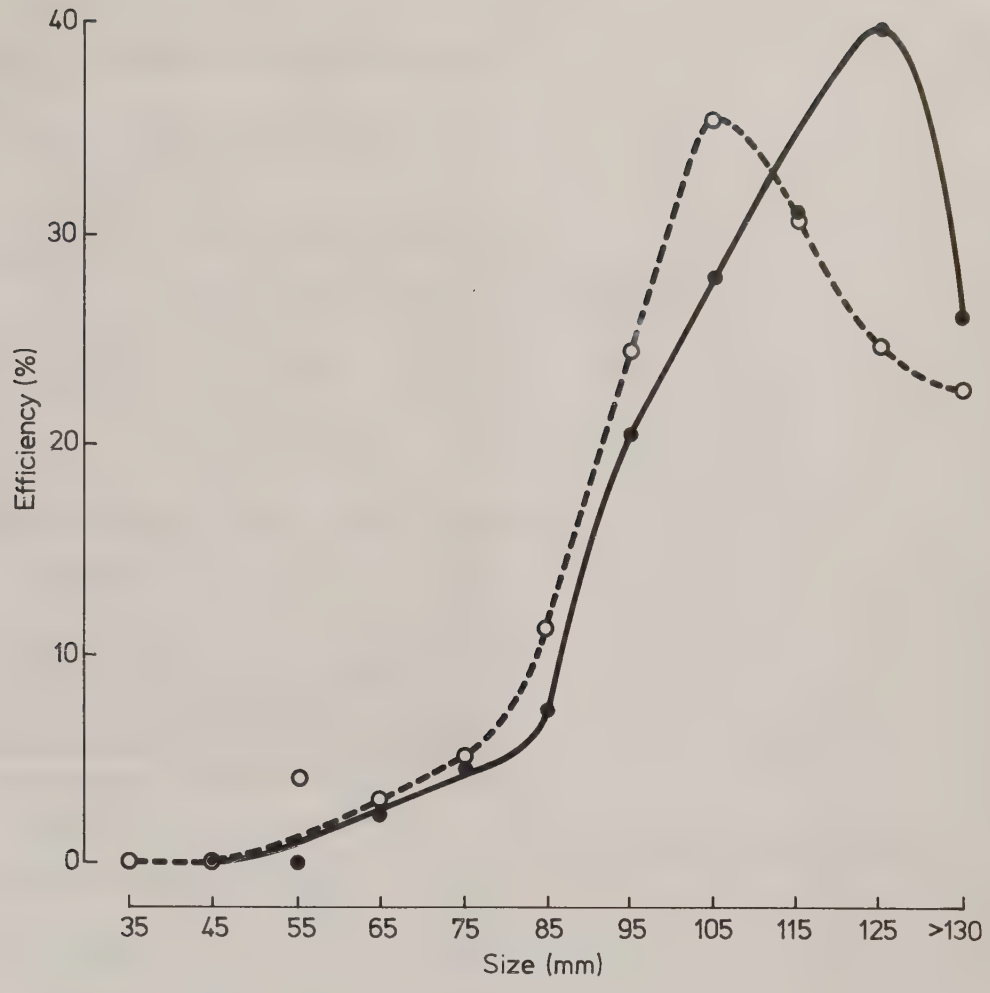

Figure 4. **Efficiency of standard dredge for different scallop sizes (10 mm groups); o - - o 1974 data; ●——● 1975 data (standard and modified dredge results combined). Few scallops greater than 130 mm were caught so that numbers were combined in calculating the efficiency.**

Efficiency of spring-loaded dredges (Tables IV, V)

The main difference between these and the standard dredge was that the spring-loaded bar did not push up a mound of material into the dredge mouth.

Table IV

Efficiencies of spring-loaded dredges fished by FRV 'Goldseeker' September 1975

Haul No	No of Dredges	Depth (m)	Towing speed (ms^{-1})	Area fished (m^2)	Density (m^2 per scallop)	Number of scallops Caught	In track	Total	Efficiency (%) Size group 〈 80 mm	〉 80 mm	overall
1	1*	18	1.0	350	3.9	27	62	89	12.5	34.3	30.3
2	1*	18.5	0.9	340	28.8	2	10	12	0	23.7	16.7
3	2	19	0.7	540	2.8	36	154	190	2.6	23.2	18.9
4	2	19	1.2	930	8.9	6	99	105	0	7.0	5.7
5	2	17	1.0	850	8.0	6	100	106	0	7.3	5.7
6	2	17	0.9	640	12.2	6	46	52	0	14.0	11.5
7	2	19	1.0	750	9.7	7	70	77	0	11.5	9.1
8	2	18	0.9	660	5.7	10	106	116	0	10.6	8.6
Totals				5050		100	646	745			
Means			0.9		6.8				2.0	16.2	13.4

* paired with standard fixed tooth dredge

Table V

Efficiency of spring-loaded tooth dredges fished by 'Accord III', July 1975.

Haul No	Depth (m)	Towing speed (ms^{-1})	Area fished (m^2)	Density (m^2 per scallop)	Side	Number of scallops Caught	In track	Total	Efficiency (%) Size group ⟨ 80 mm	⟩ 80 mm	overall
1	17-19	1.2	2910	38.3	(Port	1	38	39	—*	2.5	2.5
					(Starboard	3	34	37	0	8.3	8.1
2	23-26	1.6	4600	53.4	(Port	18	30	48	—*	37.5	37.5
					(Starboard	6	32	38	—*	15.8	15.8
3	25-26	1.4	2000	11.1	(Port	4	63	67	—*	5.9	5.9
					(Starboard	16	97	113	0	14.2	14.1
Totals			9510			48	294	342			
Means		1.4		27.8					0	14.2	14.0

Notes. Each pair of dredges, on port and starboard sides, treated separately.

*No scallops ⟨ 80 mm were caught or found in track

The teeth were narrower and longer than in the standard dredge (Table I). Only the tapered part of the teeth (about 30 mm) penetrated the sea bed and there was a gap of about 50 mm between the bar and the sea bed through which sediment could pass. The average weight of stones and other 'trash' per haul was less than half of that taken in the standard dredge (Table VI).

Table VI

Summary of all dredge efficiency estimates (expressed as percentages)

Dredge type	Vessel	Year	Number of observations	Size Group ⟨ 80 mm	⟩ 80 mm	overall	Quantity of trash per haul (kg)
Standard	'Goldseeker'	1974	13	3.3	27.0	20.7	not measured
Standard	'Goldseeker'	1975	7	3.8	23.6	18.2	14.7
Standard with wings	'Goldseeker'	1975	5	2.6	23.0	18.3	19.6
Spring-loaded	'Goldseeker'	1975	8	2.0	16.2	13.4	6.0
Spring-loaded	'Accord III'	1975	6	0	14.2	14.0	not measured

The path of the spring-loaded dredge was less obvious than that of the standard dredge, there being no ridge of deposited material at each side. In order to show the edge of the track more clearly small white-painted stones were released along it on most hauls. Most scallops found along the track were unrecessed, but 18% were still recessed because they passed between the teeth.

The overall efficiency of the dredges varied from 5.7 to 30.3% on 'Goldseeker' and from 2.5 to 37.5% on 'Accord III'. Few undersized scallops were caught but the form of the two curves in Figure 5 shows a marked difference in size selection of the dredge as fished by the two vessels. The decline in efficiency of 'Accord's' dredges for scallops $>$ 100 mm was not evident in 'Goldseeker's' spring-loaded dredge catches, despite the fact that this difference was found in 'Goldseeker's' standard dredge catches (Fig. 4). The inefficiency of 'Accord's' dredges for the larger scallops was compensated for by higher efficiency in the 90-100 mm range compared to 'Goldseeker's' dredges so that the overall efficiency of the two sets of spring-loaded gears was virtually the same - 13-14% (Table VI).

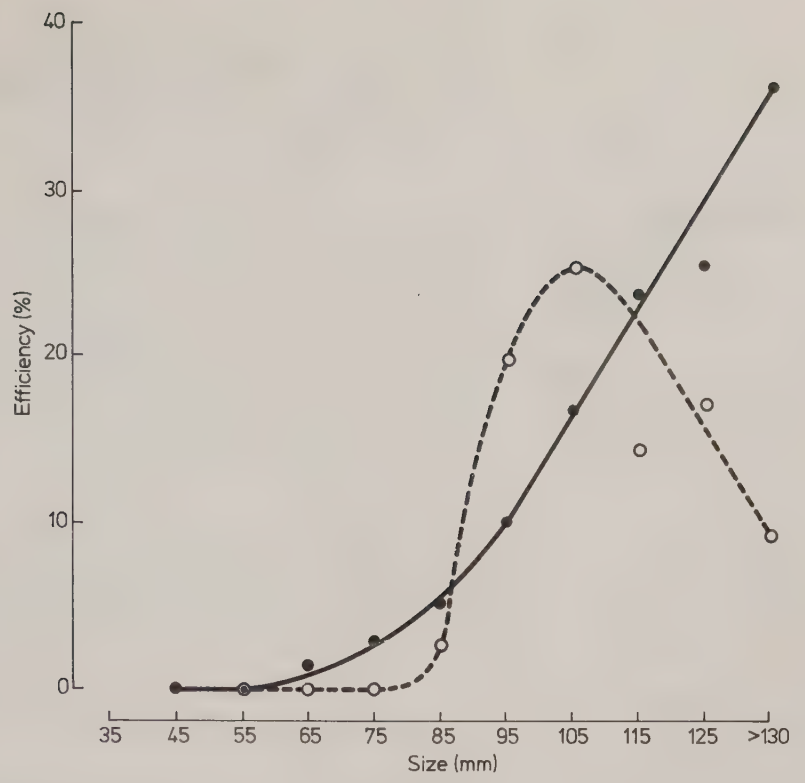

Figure 5. Efficiency of spring-loaded tooth dredges for different scallop sizes (10 mm groups). ●——● fished by 'Goldseeker'; o - - o fished by 'Accord III'.

The influence of divers on dredge efficiency

Before we can discuss the results, it is necessary to consider the possible influence of the divers on the operation of the dredges. In three hauls in 1974 and one haul in 1975, the efficiency of standard dredges was measured without divers hanging onto the gear. Five hauls employed a single dredge which two divers held onto. The remaining hauls involved a pair of dredges with one diver on each. Two divers on a dredge might be expected to have more influence than one. A comparison between the efficiency estimates obtained for these three groups of data is presented in Table VII. This reveals a slight but statistically insignificant, tendency towards higher efficiences with divers on the dredge.

Table VII

Dredge efficiency estimates for standard dredges with 1, 2 and no divers hanging onto the dredge

Haul No	Number of dredges	Number of divers per dredge	Overall efficiency (%)	Mean
6	1	0	20.0	
7	1	0	9.5	
12	2	0	10.7	14.6
1	1	0	26.1	
1	1	0	6.7	
8	2	1	11.5	
9	2	1	14.6	
10	2	1	23.6	20.3
11	2	1	33.3	
13	2	1	18.4	
1	1	2	26.0	
2	1	2	33.5	
3	1	2	14.4	23.4
4	1	2	7.2	
5	1	2	35.7	

Observations of spring-loaded dredges fished by 'Accord III' were made with both divers on the same dredge (port outer). The total catch of scallops by this dredge from three hauls was no different from that of the port inner dredge, suggesting that these dredges were not influenced by the divers.

Damage caused by the dredges and the survival of tagged scallops

The dredges caused some damage to benthic organisms on the sea bed. On most hauls a few crabs (*Cancer pagurus*) and starfish (*Marthasterias glacialis*) were broken up by the gear. The teeth also dug out several sub-surface animals including heart urchins (*Spatangus purpureus*) and the mollusc *Laevicardium crassum.* These and other organisms raked up by the teeth appeared to attract several fish and invertebrate predators including juvenile cod *Gadus morhua* (Plate IIIb), adult plaice *Pleuronectes platessa* and dogfish (Scyliorhinus canicula), whelks (*Buccinum undatum*) and hermit crabs *Pagurus bernhardus.*

The degree of shell damage of all scallops caught by 'Goldseeker' dredges and collected from the track was noted (see above). From these assessments a mean index of 'shell damage' was calculated for each group of scallops and the results are summarised in Table VIII. This shows small differences between

Table VIII

Degree of shell damage in scallops caught (in 5 min hauls) and missed by various dredges

Category	Gear	Year	scallops	% severely damaged (Scale 5)	Mean index of shell damage
Dredge-caught	Standard	1974	206	0.5	2.02
	Standard	1975	133	2.3	2.09
	Spring-loaded	1975	100	5.0	2.39
Disturbed by dredge, collected from track	Standard	1974	662	0	0.95
	Standard	1975	508	0.6	1.81
	Spring-loaded	1975	534	2.8	2.19

Note Damage assessed on arbitrary scale from 0 (no damage) to 5 (severe damage)

groups, with the heavier spring-loaded dredges tending to damage more scallops; 5% of dredge-caught and 2.8% of those left in the track were severely damaged (5 on the scale). On several occasions severely damaged scallops were already being attacked by *Marthasterias* by the time the divers swam along the track.

The survival of scallops caught or disturbed by the dredges which were tagged and returned to the sea is compared with that of scallops from unfished areas in Table IX. These results show that the highest mortality occurred in scallops caught on long hauls of an hour or more. The mortality of scallops left behind in the track averaged 4.3% compared to 2.6% in the unfished control group. It should be emphasised that these figures are based on small numbers of animals, but since most mortalities were amongst severely damaged animals, the percentage of animals with category 5 shell damage (Table VIII) is probably a good indication of mortality in those scallops missed by the gear.

Discussion

In common with similar dredges used elsewhere (Baird, 1959; Rolfe, 1969; Caddy, 1971) the efficiency of the dredges used in the Scottish scallop fishery is low, 80% or more of the scallops in the path of the gear remaining uncaught. While this is partly due to their high size selectivity (Drinkwater, 1974) it was low even for the larger marketable size scallops (Table VI). If scallops smaller than 80 m were excluded the efficiency of capture for commercial sizes varied from 14 to 27% in different gears (Table VI).

It is useful to distinguish between two factors which contribute to overall efficiency, the size selectivity by the teeth and meshes of the dredges (S) and

Table IX

Mortality of scallops collected by divers from unfished areas (A), taken from dredge tracks (B) and caught by dredge (C) - (G)

	Category	Duration of haul (mins)	Date	No tagged	Size range (mm)	Mean size (mm)	Mean index of shell damage	Number dead after 24 hours	Number dead after the number of days shown in brackets	% Mortality
A)	*Control (collected by diver from unfished areas)*	-	9 9 74	29	88-133	112	0	1	2 (6 days)	6.9
		-	10 9 75	49	65-140	101	0	0	0 (15 days)	0
			Totals	78	65-140			1	2	2.6
B)	*Collected by diver from dredge track*	-	12 9 74	25	69-140	102	0.68	0	0 (3 days)	0
			12 9 75	45	53-149	100	1.84	1	3 (13 days)	6.7
			Totals	70	53-149			1	3	4.3
C)	*Dredge-caught*	5	12 9 75	19	62-144	118	1.79	0	0 (13 days)	0
D)	*Dredge-caught*	20	12 9 75	28	83-139	109	2.18	0	0 (13 days)	0
E)	*Dredge-caught*	30	12 9 74	25	91-130	111	2.48	0	0 (3 days)	0
F)	*Dredge-caught*	60	9 9 74	28	84-138	115	not meas.	5	5 (6 days)	17.9
G)	*Dredge-caught*	80	9 9 74	20	94-135	116	not meas.	4	5 (6 days)	25.0
			Totals	120	62-144			9	10	8.3

the efficiency of capture (E). These terms were defined by Caddy (1971) as follows:

$$S = \frac{\text{Number of scallops retained}}{\text{Number of scallops entering dredge}}$$

$$E = \frac{\text{Number of scallops entering dredge}}{\text{Number of scallops in dredge path}}$$

In the above definitions the number of scallops entering the dredge includes those that are selected by the teeth. The combination of S and E gives the overall efficiency (F):

$$F = S \times E = \frac{\text{Number of scallops caught}}{\text{Number of scallops in dredge path}}$$

It is this last ratio (F) for different sizes of scallop which is shown as a percentage for each gear in Figures 4 and 5. The distinction between S and E can be illustrated more clearly with the aid of Figure 6. This shows the efficiency curve for one of the standard dredges (from Fig. 4) and possible relationships for S and E. It is likely that the selectivity would follow a sigmoid ogive characteristic of mesh selection in other types of fishing gear. This is represented by the extrapolated dotted line in Figure 6. If selection was the only factor involved one would expect the efficiency of the dredge to reach 100% for large scallops. Clearly the overall efficiency of the standard dredge was limited by the second factor E, shown as a broken line in Figure 6. The divers observed that many large scallops were pushed aside by the toothed bar especially when a mound of sediment built up in front (Plate IV). Thus, many scallops large enough to be retained by the meshes never entered the bag. There is some evidence that above a certain size E is inversely proportional to scallop size. This is illustrated in three of the curves in Figures 4 and 5 by the lower efficiency for the largest scallops. Large scallops are generally more deeply recessed into the sea bed (Chapman, unpublished observations) and they may be less readily dug out by the teeth.

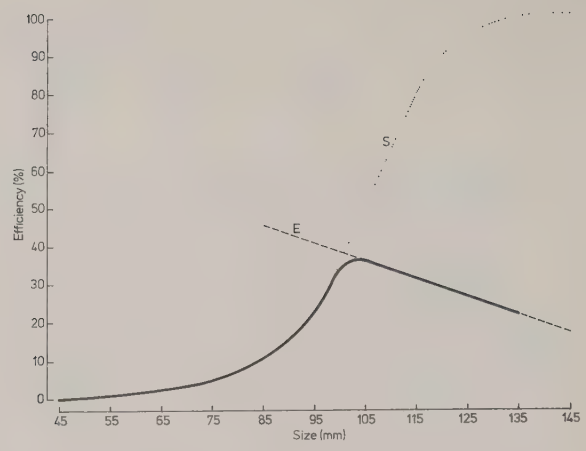

Figure 6. Diagram to show the overall efficiency of standard dredges fished by 'Goldseeker', 1974 (Solid line) composed of two components, selectivity (S) and catching efficiency (E).

It is clear from Figure 5 that similar gears may have very different efficiency curves when fished by two vessels on different grounds. The efficiency curve for the spring-loaded dredges fished by 'Goldseeker' does not turn down in contrast to that for similar gear fished by 'Accord III'. This suggests that the former curve is a function of selection alone with no influence of any catching efficiency component. The reasons for these variations were not clear because there were several differences in the manner of gear rigging and handling such as the presence of wheels on the towing bar employed by 'Goldseeker'. This maintained a constant angle of attach of the teeth whereas this varied considerably during the hauls of 'Accord III'. The commercial vessel also fished on harder ground and a much greater quantity of stones was picked up compared with that gathered by 'Goldseeker's' spring-loaded dredges. It was observed that large stones often blocked the spaces between the teeth of 'Accord's' dredges and caused local build-up of sediment. This was seldom observed on the smooth grounds fished by 'Goldseeker' and consequently very few scallops were pushed aside by the toothed bar of 'Goldseeker's' spring-loaded dredges. It is also likely that less selection took place in the 'bag' of 'Accord's' dredges because of the greater quantity of stones caught, tending to block the belly ring and net meshes. The tendency for the spaces between the teeth to become blocked by stones would be expected to reduce catching efficiency because periodically the teeth would be cleared by flexing back against the springs. This action would tend to lose some commercial sized scallops and a larger loss would be expected from this cause on the rougher grounds fished by 'Accord III' than on those fished by 'Goldseeker'. Thus the nature of the sea bed appears to be of major importance in determining both selectivity and efficiency of capture of the gear and probably accounts for many of the differences in the results presented in Figure 4 and 5.

The comparison between the different gears (Table VI) suggests that the standard dredges were more efficient overall than the spring-loaded dredges. It is possible that this resulted, at least in part, from the influence of the divers holding onto the gear as mentioned earlier. Table VII shows that the average efficiency of the standard dredge was 14.6% with no divers present and this is comparable to the average efficiency of the spring-loaded dredges. A possible explanation of the effect of divers is that the flow of water under them tended to lift the dredges, thus reducing the penetration of the teeth

into the sediment and hence the build-up of deposit in the mouth of the standard dredge. A similar effect was noted when the towing bar and dredges picked up large quantities of *Laminaria* fronds, eventually causing the whole gear to rise off the sea bed. It is likely that the spring-loaded dredges were less liable to influence by the divers because they are heavier and in any case their teeth do not penetrate the sediment to the same extent.

Irrespective of any efficiency comparisons, our observations confirm that the spring-loaded dredge is a superior gear for the wide range of sediments now being fished. It takes a much smaller quantity of stones and 'trash' and has a larger 'bag' compared to the standard dredge so that it fishes for much longer before becoming full. It is also less liable to damage on rocky ground. Spring-loaded dredges also have the advantage that more selection occurs through the spaces between the teeth than in the standard dredge. It must be emphasesed that our observations were mainly carried out on smooth grounds composed of fine sediments using hauls of relatively short duration. Most commercial fishing takes place on rougher ground with much longer hauls. The changes in selectivity and catching efficiency as the catch and 'trash' accumulates during long hauls requires further investigation.

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Summary

The efficiency of standard and spring-loaded scallop dredges is low. Standard dredges with a fixed tooth bar caught about 20% of all scallops in their path. Dredges with a spring-loaded toothed bar caught 13%. Both gears were highly selective and, at most, only 4% of scallops below 80 mm in size were caught. For commercial sized scallops ($\geqslant$80 mm) the average efficiencies were 25% for standard and 15% for spring-loaded dredges. Most of the scallops were pushed aside by the build-up in sediments in front of the toothed bar of the standard dredge. A small mortality (about 3%) occurred in severely damaged scallops missed by the dredges. The overall efficiency of the dredge can be divided into two components: the selectivity of the teeth and meshes (S) and the catching efficiency (E). The results for different gears are discussed in relation to these components and it is suggested that both are strongly influenced by the nature of the sea bed.

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